Faculty of Mechanical Engineering

LOW VELOCITY IMPACT RESPONSE OF OIL PALM EMPTY FRUIT BUNCH FIBRE METAL LAMINATES

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DECLARATION

I declare that this thesis entitled “Low Velocity Impact Response of Oil Palm Empty Fruit Bunch Fibre Metal Laminates” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :……..

Name : NUR FADZILA BINTI HUSSAIN

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : …….

Supervisor name: ASSOC. PROF. DR. SIVAKUMAR A/L DHAR MALINGAM

Date : ……

DEDICATION

Specially dedicated to my beloved husband and sons, parents, family and friends for their love, supports and prayers.

ABSTRACT

The search for new environmental-friendly materials is ever growing. Hence, the use of natural fibre reinforced polymer composite in fibre metal laminates (FML) fields is the current interest. The potential and performance of FML based natural fibre have been investigated. Recently, the applications of lightweight criteria of FML in mechanical properties attract other industries including the automotive industry. This industry demands lightweight materials for vehicles concerning with sustainable and low manufacturing cost. Hence, FML with new alternative materials is required for this industry. Since FML is desired to be used in automotive or other forms of transport vehicles, the understanding of its behaviour under impact loading was relevant and important. This study investigated the effect of different stacking configuration (2/1, 3/2 and 4/3) subjected to quasi static indentation test and low velocity impact test for oil palm empty fruit bunch fibre reinforced-metal laminate (OPFML) system. Experiments were performed with a constant strain rate of 1.0mm/s of static loading and varying impact velocities at 1.98m/s, 2.80m/s and 3.43m/s of dynamic loading. The similar hemispherical indenter size with 12.7mm was used for both testing. The indentation behaviour and impact resistance of OPFML panels were presented based on the peak load, maximum displacement, energy absorption and specific energy absorption values. For both testing, it is clear the highest stacking configuration, OPFML 4/3 showed the highest value of the peak load, energy absorption and specific energy absorption values due to the stiffer behaviour. An examination of different impact velocities under low velocity impact test revealed the highest velocity of 3.43m/s which showed the highest value of energy absorption and specific energy absorption for each stacking configuration. From this study, it is found that the failure mode of quasi static indentation test showed the similar trend of each stacking configuration whereas the failure mode of low velocity impact test showed the different trends for each velocity. As a conclusion, the stacking configuration influenced the indentation behaviour and impact resistance of OPFML panels. Hence, oil palm empty fruit bunch fibre is suitable as a new raw material for the composite part in automotive industry application.

ABSTRAK

Pencarian tentang bahan baru yang mesra alam semakin meningkat. Oleh itu, penggunaan polimer komposit berasaskan serat semulajadi di dalam bidang lamina logam serat (FML) semakin diminati pada masa kini. Potensi dan kebolehan lamina logam serat berasaskan polimer komposit serat senulajadi telahpun dikaji. Kini, lamina logam serat (FML) yang bersifat ringan dan mempunyai ciri-ciri mekanikal yang baik telah menarik perhatian industi termasuk industri automotif. Industri ini memerlukan bahan ringan yang bersifat lestari (sustainable) dan mempunyai kos pembuatan yang rendah untuk sesebuah kenderaan. Oleh itu, lamina logam serat dengan alternatif bahan baru diperlukan untuk industri ini. Kajian ini mengkaji tentang kesan bilangan lapisan lamina yang berbeza (2/1, 3/2 dan 4/3) terhadap ujikaji lekukan statik dan ujikaji kelajuan hentakan rendah untuk lamina logam serat berasaskan polimer komposit serat tandan sawit kosong bertetulang polipropilena (OPFML). Mesin bertekanan panas telah digunakan di dalam kajian ini untuk proses lekatan panel OPFML pada suhu 155 °C, tekanan 1 kg/cm² dan masa 4 minit dan juga digunakan ketika fabrikasi komposit pada suhu 185°C, tekanan 35kg/cm^2 dan masa 8 minit. Ujikaji ini dilakukan dengan kadar tegangan tetap iaitu 1mm/s untuk daya statik dan kadar halaju hentakan yang berbeza iaitu 1.97m/s, 2.8m/s dan 3.43m/s untuk daya dinamik. Kedua-dua ujikaji ini meggunakan alat hentakan diameter hemisfera yang sama iaitu 12.7mm. Sifat lekukan dan rintangan hentakan panel OPFML telah dibincangkan berdasarkan nilai puncak beban, jarak maksima, serapan tenaga dan serapan tenaga spesifik (SEA). Kedua-dua ujikaji menunjukkan bahawa bilangan lapisan lamina yang banyak, OPFML 4/3 mempamerkan nilai puncak beban, serapan tenaga dan serapan tenaga spesifik yang tinggi berdasarkan sifat kekerasan yang terhasil. Bagi ujikaji ujian kelajuan hentakan rendah pula, halaju hentakan yang paling tinggi iaitu 3.43m/s mempamerkan nilai serapan tenaga dan serapan tenaga spesifik yang tinggi untuk setiap bilangan lapisan lamina. Hasil kajian juga menunjukkan jenis kegagalan panel OPFML oleh ujikaji lekukan statik adalah sama manakala jenis kegagalan oleh ujikaji kelajuan rendah adalah berbeza untuk setiap kadar halaju. Sebagai rumusan, bilangan lapisan lamina mempengaruhi sifat lekukan dan rintanagn hentakan panel OPFML. Oleh itu, kajian ini menunjukkan bahawa serat tandan sawit kosong adalah sesuai sebagai bahan asas baru untuk bahagian komposit dalam aplikasi industri automotif.

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FML	-	Fibre metal laminates
OPFML	-	Oil palm empty fruit bunch fibre metal laminates
TFML	-	Thermoplastic fibre metal laminates
OPC	-	Oil palm fibre reinforced polypropylene composite
NFRP	-	Natural fibre reinforced polymer

LIST OF PUBLICATIONS

A. Journal paper

1. Hussain, F., Sivakumar, D., Daud, M.A. Irulappasamy, S., Klósak, M., 2018. Indentation Behaviour of Eco-Friendly Fibre Metal Laminates In Different Stacking Configurations. *Defence S&T Technical Bulletin*, Vol. 11, Num. 2.
2. Sivakumar, D., Hussain, F., Ng, L.F., Chua, J.W. Dzulfakarudin, M.I., 2018. Tensile and Flexural Performance of Polypropylene Based Oil Palm Fibre Reinforced Metal Laminates. *International Review of Mechanical Engineering* (IREME) 12 (2), 155-16.
3. Hussain, F., Sivakumar. D., 2018. Low Velocity Impact Response of Eco-Friendly Fibre Metal Laminates. *Materials Research Expres*s. Manuscript in review.

B. Proceeding paper

1. Hussain, F., Sivakumar, D.,* Daud, M.A., Selamat, M.Z., 2016. Tensile Performance of Palm Oil Fiber Metal Laminate. Proceeding of Mechanical Research Day 2016.
2. Hussain, F., Sivakumar, D.,* Daud, M.A., Selamat, M.Z., 2015. Study of Interfacial Shear of Aluminium/Oil Palm Empty Fruit Bunch Fiber Reinforced Polypropylene Fiber Metal Laminates": *Applied Mechanics and Materials*

3. Hussain, F., Sivakumar, D.,* Daud, M.A., Khatiravan, S., 2015. Charpy Impact Response of Oil Palm Empty Fruit Brunch Fiber Reinforced Metal Laminate System*: Proceeding of Mechanical Research Day 2015.*

C. Conference

1. Hussain, F., Sivakumar, D.,* Daud, M.A., Selamat, M.Z. (MIMT 2015), 6-7 March 2015. Study Of Interfacial Shear Of Aluminium/Oil Palm Empty Fruit Bunch Fibre Reinforced Polypropylene Fibre Metal Laminates": Applied Mechanics and Materials: International Conference on Mechanical, Industrial and Technologies.

D. Poster Conference

1. Mechanical Research Day 2016, Center of Advance, Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka (Presenter)
2. Mechanical Research Day 2015, Center of Advance, Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka (Presenter)

E. Exhibition

1. Sivakumar Dhar Malingam, Sivarao Subramaniam, Fadzila Hussain (Presenter), Ng lee Feng, S.Khatiravan "Novel Palm Oil Reinforced-Metal Laminate Systems": UTeMEX 2015: Silver medal

CHAPTER 1

INTRODUCTION

1.1 Introduction

Innovation of materials in different ways is rapidly performed nowadays. The main purpose of material innovation is to improve performance or reduce any cost that can influence the outcomes. Environmental sustainability or green technology knowledge is a priority in many fields nowadays and it is closely related to environmental issues such as water, noise and air pollution. Hence, for sustainable development, all factors that can cause pollution need to be analysed.

1.2 Background research

Currently, global warming level becomes critical. One of the global warming causes is carbon dioxide (CO_2), a gas emission of burning gasoline from vehicles. CO_2 is one of the greenhouse gases that is increasing in atmospheric concentration. The German Institute for Energy and Environmental Research analysis has discovered a 100 kilogram reduction in the mass of a standard passenger car results in fuel savings of between 300 to 800 litres over the lifetime of the vehicle, while for taxis and city buses, these figures are significantly higher at over 2500 litres (Helms and Lambrecht, 2006). A 100 kilogram mass reduction also reduces a standard car's greenhouse-gas emissions by approximately nine grams of CO_2 per kilometre. This scenario proves that reduction of vehicle mass can significantly contribute to the reduction of greenhouse-gas emissions. The International Aluminium Institute reported that approximately 23% of CO_2 gas emissions from fuel

combustion are generated by transportation sector, which is continuously growing (Helms and Lambrecht, 2006). The energy required to power motor vehicles is four times more than the energy required for producing them, consequently over 80% of the transport sector's greenhouse-gas emissions are produced during the vehicle's operating life (Helms and Lambrecht, 2006). As a result, the reduction in vehicle weight is critical to reduce the CO_2 gas emissions. Hence, in an effort to achieve major weight reduction, the use of lightweight material in automotive industry becomes paramount. Therefore, a lightweight material such as fibre metal laminates is currently being studied.

Generally, fibre metal laminate (FML) is a laminated structure material which comprises thin metal layer (laminates skin) and fibre reinforced polymer (FRP) composite (laminates layers). According to Ferrante et al. (2016), the key of FMLs is to combine superior fatigue resistance of composite materials with plastic behaviour and durability of metals. Their development is mainly due to the need to improved poor fatigue resistance of aluminium alloys through the use of alternate stacking of thin high- strength metal sheet bonded together with alternating fibre-reinforced composite layers. This bi-material is bonded using selected adhesive subject to the laminates materials. There are several advantages of FML that make it very interesting such as; high specific strength, better damage tolerance to fatigue crack growth, fire resistance, blunt notch strength and formability (Sadhigi et al., 2012).The development of FML began at Delf University of Technology in the late 1970's when Vlot successfully produced the first panel of FML known as aramid reinforced aluminium laminate (ARALL) (Laliberte et al., 2002). Besides ARALL, two more types of traditional FMLs which are commercially accessible namely carbon reinforced aluminium laminates (CARALL) and glass reinforced aluminium laminates (GLARE). At the beginning of its production, FML was initially applied for aerospace industry. An example, ARALL is used for aircraft structural parts,

which are sensitive to the fatigue loads like wing skin and pressurized fuselage cabin while CARALL it used for impact absorbers of helicopter struts and aircraft seats. The applications of GLARE in aeroplane parts include main fuselage skin, leading edges of the horizontal and vertical tail planes as shown in Figure 1.1 (Chandrasekar et al., 2017).

Figure 1.1**:** Application of GLARE (Eswara and Wanhill, 2016)

Nevertheless, the composite laminates layers of ARALL, CARALL and GLARE consist of thermoset polymer resin and synthetic fibre reinforcement. Both of these materials have several limitations. Based on previous study, laminates core in traditional FML require long processing cycle during composite curing process, low interlaminar fracture toughness properties as well as difficulties associated with repair and environmental issues (Cortes, 2014). Long processing cycle causes the increase in manufacturing cost. Hence, realizing that low production process cycle time and priority of sustainable materials are important, an alternative to improve FML constituents materials is essential. The requirement for material with low processing cycle in FML fabrication

improvement is paramount. Replacing thermoset composite material with thermoplastic has significant contribution in FML fabrication improvement.

Thermoplastic based composite is primarily an option for FML laminates layers because this material is able to shape in a shorter processing time and can be moulded and bonded to the metal skin (Cortes and Cantwell, 2005)**.** These advantages clearly offer an attractive option for reducing both the cycle time and associated manufacturing costs (Reyes and Gupta 2009)**.** Langdon et al. (2015) stated that FMLs based thermoplastic also have a good chemical resistance, rapid manufacturing, recyclability and elevated fracture toughness. Another limitation of traditional FMLs is environmental issues as the reinforcement of composites is made of synthetic materials. The synthetic materials are non-environment friendly because these materials are non-biodegradable and have poor recycling. These materials are also costly to produce and can give bad effect on human health. Rozman et al. (2004) stated that natural fibres offer various advantages such as low density, low cost, biodegradability, acceptable specific properties, better thermal and insulating properties and low energy consumption during processing.

Hence, to produce environment-friendly materials, FML based on natural fibre reinforced thermoplastic composite is proposed. Since the oil palm empty fruit bunch (OPEFB) fibre still not been fully explored as biodegradable polymer composites (Faizi et al., 2016), this studied used oil palm empty fruit bunch fibre reinforced polypropylene composite as a laminates layers of FMLs studied here. The OPEFB fibre was selected in this studied because apart from its eco-friendly, renewable nature, cheap, low density, better thermal and insulating properties, the processes of converting OPEFB's fibre into composite also promotes low energy consumption (Razman et al., 2004). In the other hand, the good mechanical properties of polypropylene such as dimensional stability, low density, high heat distortion temperature, excellent process ability, flame resistance and

transparency (De Fatema et al., 2015) make this polymer was chosen as a composite matrix in this studied. Faizi et al. (2016) proved that OPEFB polymer composites had huge potential for the energy absorption application on low velocity impact based on their findings from previous research in OPEFB polymer composites. Hence, this study will investigated the mechanical behaviour of FML based on OPEFB polypropylene composites under quasi static indentation test and low velocity impact test.

1.3 Problem statement

Recently, the lightweight criteria and good in mechanical properties of FML attract others industries and applications including automotive industry. This industry demands lightweight materials for vehicles with concerns on sustainability. Since the application of polymer composite in the automotive field is very important for reduce operating cost and related with FML applications, this studied would be produced the FML based on natural fibre reinforced polymer composites. Hence, the oil palm empty fruit bunch fibre (OPEFB) reinforced polypropylene composite was selected as a FML materials constituents in this studied.

The main reason of choosing the OPEFB fibre in this studied it is because this fibre has high cellulose content and has potential as natural fibre resources. High cellulose content and high toughness value of OPEFB fibres make it suitable for application in polymer composites. These fibres also available in abundance, renewable, nontoxic, and low cost. The others reason is because the oil palm composite has wide application in automotive component due to their low weight, design flexibility, corrosion resistance, and cost effectiveness. Besides that, finding the useful applications for oil palm empty fruit bunch will surely alleviate environmental problems related to the disposal of oil palm wastes and produce materials that could offer favourable balance quality,

and cost. In addition, the oil palm empty fruit bunch (OPEFB) polymer composite also had a potential in energy absorption application that very important for impact behaviour characteristics and related with automotive application (Faizi et al., 2016)

Since the FML and oil palm composites was related in automotive applications, this studied would be investigated the impact behaviour of oil palm empty fruit bunch fibre metal laminates (OPFML) system under static and dynamic loading. The reason behind this is because when a FML is desired to be used in an automotive or other forms of transport vehicles, then understanding of its behaviour under impact loading was relevant and important. However, the impact behaviour of FML based on oil palm fibre reinforced polypropylene composites is yet to be well understood. Since the low velocity impact is the most common type of impact occurring in vehicles, there is great need to study the low velocity impact resistance of FML based on oil palm empty fruit bunch fibre reinforced polypropylene composite in order to characterise their impact response.

1.4 Objectives

The objectives of the research are on follows:

i. To analyse the indentation resistance under quasi static test of the established fibre metal laminate based on natural fibre reinforced thermoplastic.

ii. To analyse the impact response under low velocity impact test of the established fibre metal laminate based on natural fibre reinforced thermoplastic.

iii. To investigate the type of failure modes of the established fibre metal laminate based on natural fibre reinforced thermoplastic.